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**Bogert**

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(54) **LOCKED SEGMENTS PUSHABLE  
STENT-GRAFT**

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USPC ..... 623/1.16, 1.15, 1.13, 1.2  
See application file for complete search history.

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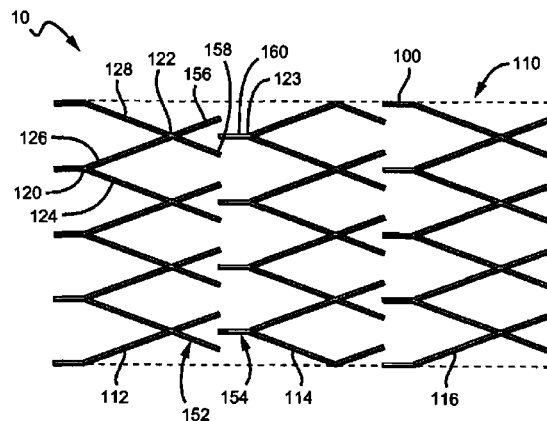
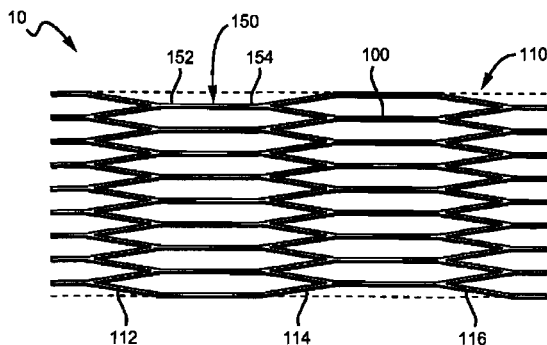
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Property; Buchalter Nemer

(57) **ABSTRACT**

An implantable prosthesis includes a scaffold with a plurality of expandable segments axially spaced apart along a substrate, adjacent segments connected by one or more support members when the prosthesis is in a collapsed configuration and disconnected when the prosthesis is in an expanded configuration.

**18 Claims, 5 Drawing Sheets**



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FIG. 1A

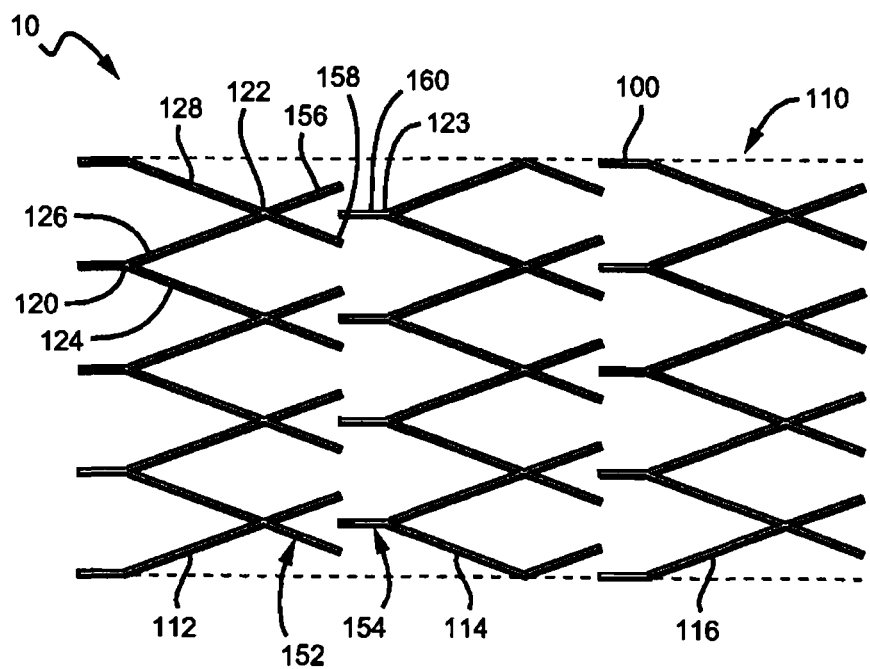
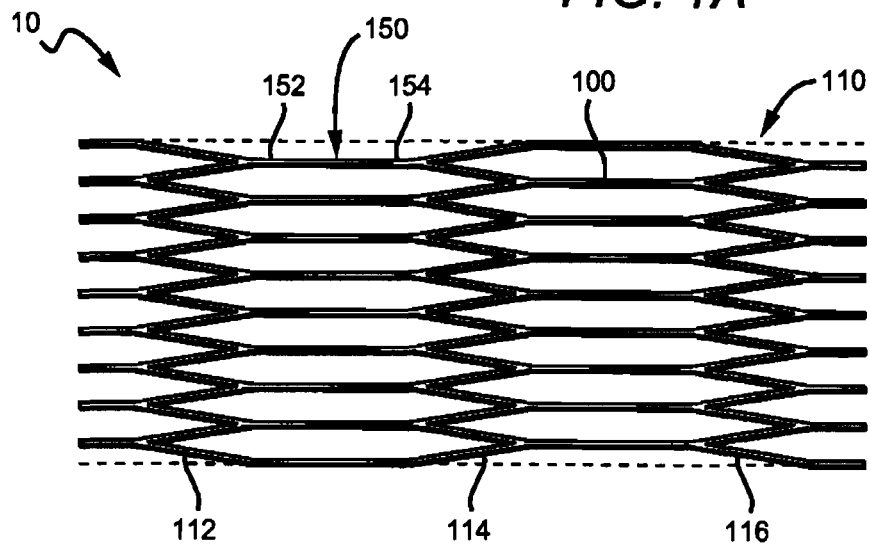


FIG. 1B

FIG. 1C

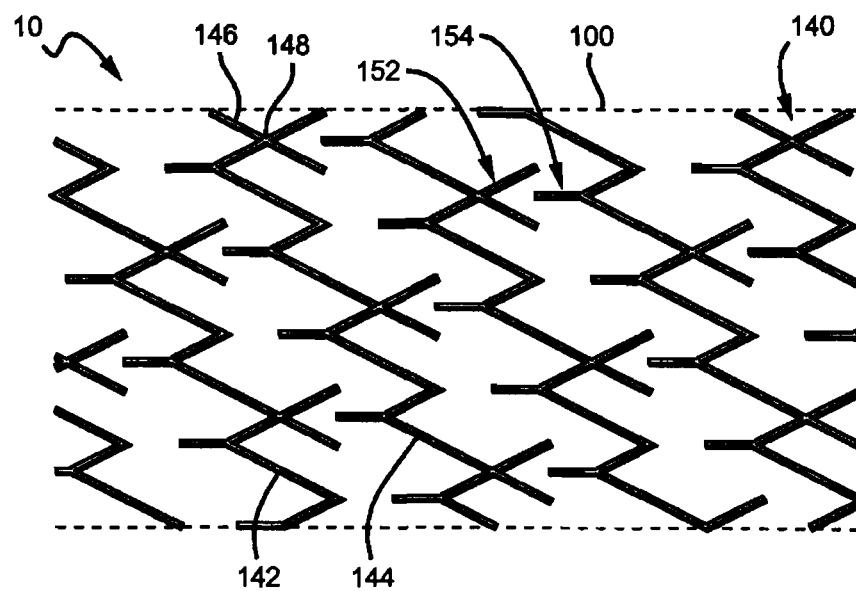
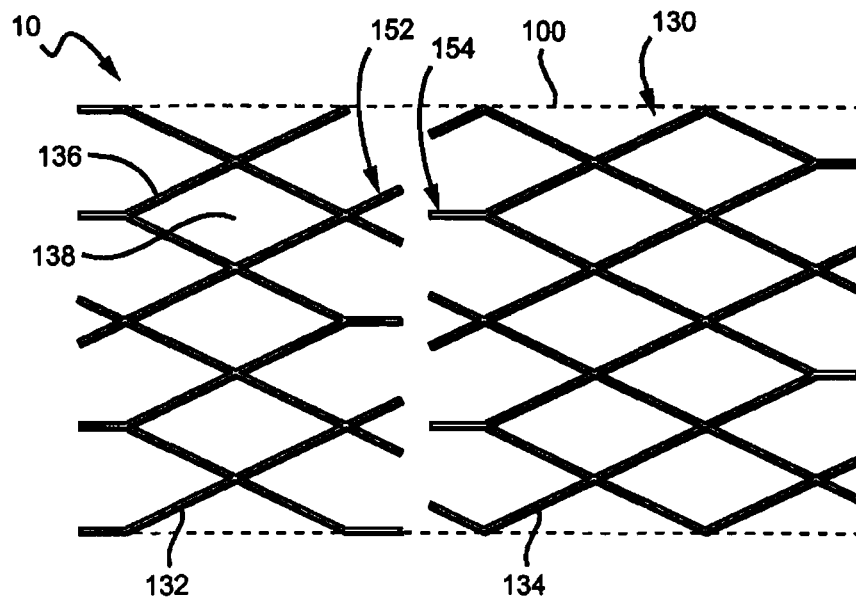
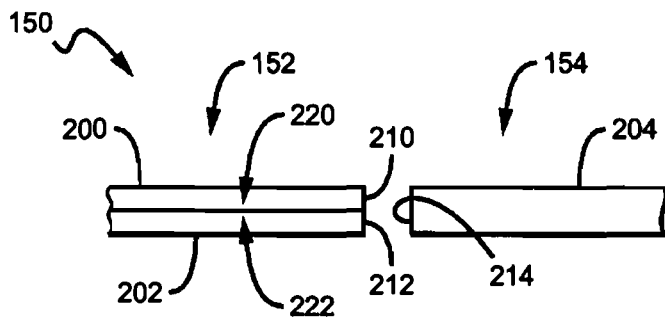
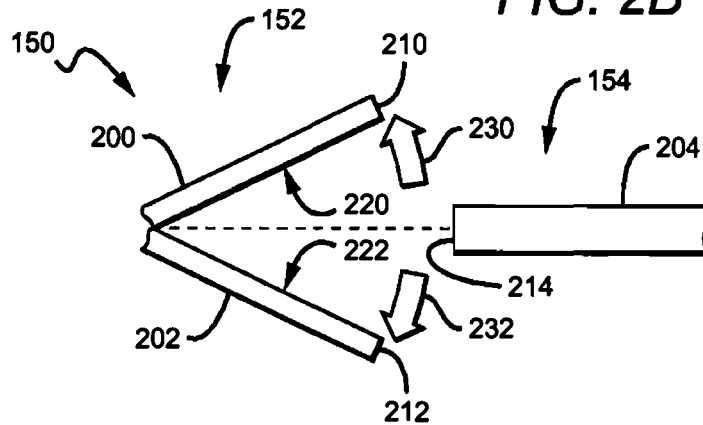


FIG. 1D

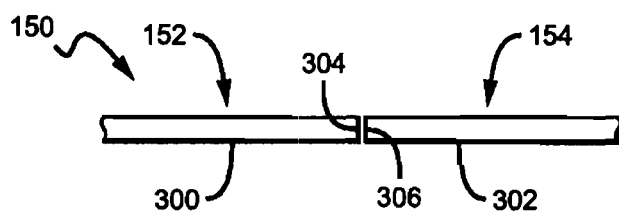
**FIG. 2A**



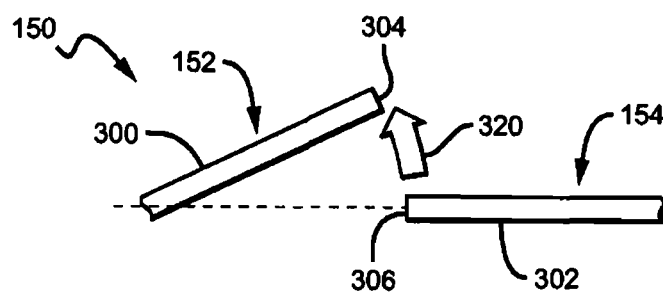
**FIG. 2B**

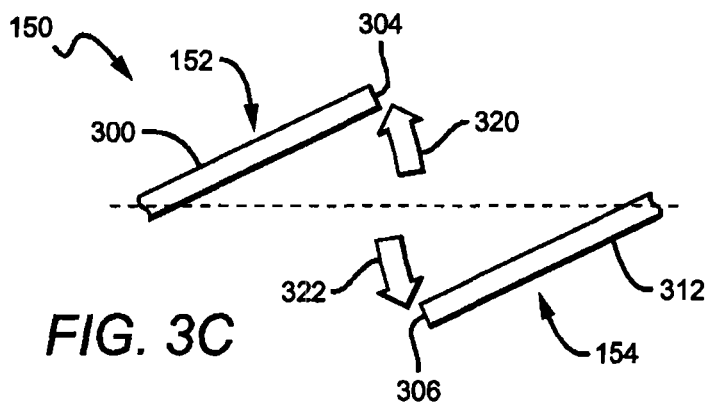


**FIG. 3A**

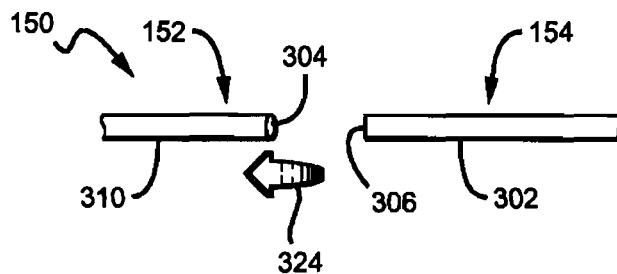


**FIG. 3B**

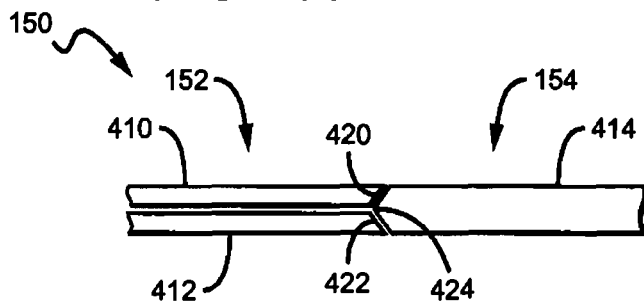




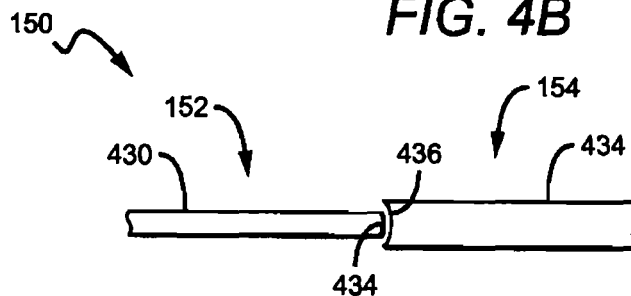
**FIG. 3D**



**FIG. 4A**



**FIG. 4B**



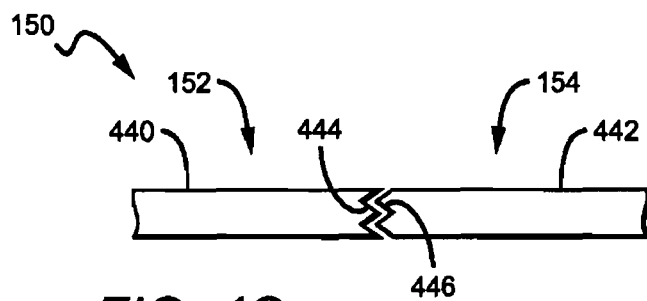


FIG. 4C

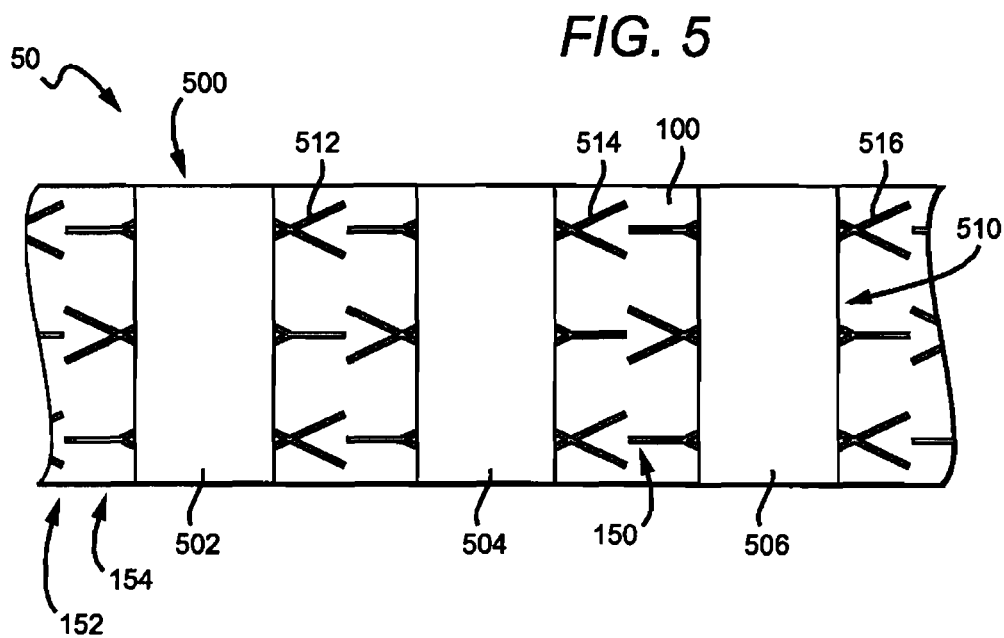


FIG. 5

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# LOCKED SEGMENTS PUSHABLE STENT-GRAFT

## PRIORITY

This application is a U.S. national stage application under 35 USC §371 of International Application No. PCT/US2008/067620, filed Jun. 20, 2008, claiming priority to U.S. Provisional Patent Application No. 60/936,889, filed Jun. 22, 2007, each of which is incorporated by reference in its entirety into this application.

## BACKGROUND

Intraluminal prostheses used to maintain, open, or dilate blood vessels are commonly known as stents. Stent constructions generally include lattice type cylindrical frames that define a plurality of openings. Common frameworks for stents include, for example, individual rings linked along the length of the stent by a linking member, a continuous helically wrapped member (that may include one or more linking members), a braid or a mesh formed into a tubular structure, and a series of interconnected struts. Stents may be formed by arranging one or more members in a pattern along a longitudinal axis to define essentially a cylinder and connecting the one or more members or otherwise affixing them in position (e.g., interconnecting with a filament). Stents may also be formed by cutting openings into a tube of material (e.g., shape memory).

Stents may have self-expanding and/or balloon expandable properties. Self-expanding stents are delivered to a blood vessel in a collapsed condition and expand in vivo following the removal of a constraining force and/or in the presence of an elevated temperature (due to material properties thereof), whereas balloon expandable stents are generally crimped onto a balloon catheter for delivery and require the outwardly directed force of a balloon for expansion. Stents can be made of various metals and polymers and can include a combination of self-expanding and balloon expandable properties.

Synthetic vascular grafts are routinely used to restore the blood flow in patients suffering from vascular diseases. For example, prosthetic grafts made from expanded polytetrafluoroethylene (ePTFE) are commonly used and have shown favorable patency rates, meaning that depending on a given time period, the graft maintains an open lumen for the flow of blood therethrough. Grafts formed of ePTFE include a microstructure characterized by spaced apart nodes connected by fibrils, the distance between the nodes defined as internodal distance (IND), and are generally extruded either as a tube or as a sheet or film that is fashioned into a tube. Grafts can also be created from fibers woven or knitted into a generally tubular shape.

It is known in the art to use stents in combination with vascular grafts to form stent-grafts. Because stent-grafts are often intraluminally deployed in vessels of varying sizes and tortuosity, flexibility can be an important consideration. Flexibility can be imparted to a stent-graft in a variety of ways, including, for example, connection of the stent to the one or more graft layers, configuration of the stent and/or graft layer(s), spacing of the stent struts, rings, or members along the length of the graft(s), etc. For example, U.S. Pat. No. 6,398,803 and U.S. Pat. No. 6,770,087 to Layne et al., which are incorporated by reference in their entirety into this application, describe a graft layer with openings to enhance flexibility. U.S. Pat. No. 6,558,414 to Layne, which is

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incorporated by reference in its entirety into this application, describes another type of graft layer to enhance flexibility.

Another important consideration in the design of a stent-graft is the ability of the stent to withstand stress and fatigue, caused, for example, by plastic deformations occurring at strut junctions when the stent is subjected to circumferential forces. Stent strength can be enhanced through material choice, stent configuration, arrangement and configuration of graft layers, connecting members between stent members, etc. Yet another consideration in the design of a stent-graft is its columnar strength in the compressed configuration to enable the stent-graft to be pushed out of a delivery sheath, for example, without buckling or deforming. This consideration, however, must be balanced with flexibility considerations, such as those discussed above.

The following references relate to stents and stent-grafts: U.S. Pat. No. 5,591,197 to Orth et al.; U.S. Pat. No. 6,695,833 to Frantzen; U.S. Patent Application No. 2003/0229390 to Ashton et al.; and U.S. Patent Application No. 2004/0230288 to Rosenthal, each of which is incorporated by reference in its entirety into this application.

Applicants have recognized that it would be desirable to provide a stent-graft that is relatively stiff in a collapsed configuration and more flexible in a deployed expanded configuration, embodiments of which are described herein along with methods of making same.

## BRIEF SUMMARY

Accordingly, stent-grafts are described herein with different columnar strengths in the collapsed and expanded configurations, the columnar strength of the stent-graft in the collapsed configuration greater than the columnar strength of the stent-graft in the expanded configuration.

In one embodiment, an implantable prosthesis having an expanded configuration defining an expanded perimeter and a collapsed configuration defining a collapsed perimeter smaller than the expanded perimeter includes a generally tubular substrate defining a longitudinal axis, a plurality of expandable segments disposed over the substrate and spaced apart along the longitudinal axis, and a plurality of support members connected to the expandable segments and extending transversely therefrom, each support member including a first element connected to a first expandable segment and a second element connected to a second expandable segment adjacent to the first expandable segment, the first element and second element engaged in the collapsed configuration and disengaged in the expanded configuration.

In another embodiment, an implantable prosthesis having an expanded configuration defining an expanded perimeter and a collapsed configuration defining a collapsed perimeter smaller than the expanded perimeter includes a generally tubular substrate defining a longitudinal axis, a scaffold disposed over the substrate, including a plurality of support members positioned generally parallel to the longitudinal axis, each support member including a first element engaged with a second element in the collapsed configuration, at least one of the first and second elements moving to a position generally oblique to the longitudinal axis in the expanded configuration such that the first and second elements are disengaged.

In yet another embodiment, a stent-graft exhibits a first columnar strength in a collapsed configuration and a second columnar strength less than the first columnar strength in an expanded configuration, the stent-graft including a plurality of spaced apart support members connecting adjacent expandable segments, each support member including a first



element coupled to a second element in the collapsed configuration, the first and second elements uncoupling upon expansion of the stent-graft to the expanded configuration.

In one embodiment, a method of implanting a stent-graft having an expanded configuration defining an expanded perimeter and a collapsed configuration defining a collapsed perimeter smaller than the expanded perimeter includes placing a stent-graft in a delivery device in the collapsed configuration, the stent-graft including a generally tubular substrate defining a longitudinal axis, a scaffold disposed over the substrate, including a plurality of support members positioned generally parallel to the longitudinal axis, each support member including a first element engaged with a second element in the collapsed configuration, delivering the stent-graft to a desired location, and expanding the stent-graft to the expanded configuration, the first element disengaging from the second element.

These and other embodiments, features and advantages will become more apparent to those skilled in the art when taken with reference to the following more detailed description of the invention in conjunction with the accompanying drawings that are first briefly described.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A is a partial side view of one embodiment of an implantable prosthesis in a representative compressed configuration, including expandable segments with support members engaged.

FIG. 1B is a partial side view of the embodiment of FIG. 1A in a representative expanded configuration, including expandable segments with support members disengaged.

FIG. 1C is a partial side view of another embodiment of an implantable prosthesis in a representative expanded configuration, including a scaffold with expandable segments with the support members disengaged.

FIG. 1D is a partial side view of another embodiment of an implantable prosthesis in a representative expanded configuration, including a scaffold with expandable segments with the support members disengaged.

FIG. 2A is an enlarged view of a support member, including a first element and second element, when the prosthesis is in a collapsed configuration.

FIG. 2B is a view of the support member of FIG. 2A when the prosthesis is in an expanded configuration.

FIG. 3A is a view of another embodiment of a support member when the prosthesis is in a collapsed configuration.

FIG. 3B is a view of one configuration of the support member of FIG. 3A when the prosthesis is in an expanded configuration.

FIG. 3C is a view of another configuration of the support member of FIG. 3A when the prosthesis is in an expanded configuration.

FIG. 3D is a view of yet another configuration of the support member of FIG. 3A when the prosthesis is in an expanded configuration.

FIG. 4A is a view of one embodiment of a support member when the prosthesis is in a collapsed configuration.

FIG. 4B is a view of another embodiment of a support member when the prosthesis is in a collapsed configuration.

FIG. 4C is a view of yet another embodiment of a support member when the prosthesis is in a collapsed configuration.

FIG. 5 is a partial side view of one embodiment of an implantable prosthesis including a scaffold with circumferential bands disposed about an outer surface.

#### DESCRIPTION OF THE PREFERRED EMBODIMENTS

The following description should be read with reference to the drawings, in which like elements in different drawings are identically numbered. The drawings, which are not necessarily to scale, depict selected embodiments and are not intended to limit the scope of the invention. The description illustrates by way of example, not by way of limitation, the principles of the invention. This description will clearly enable one skilled in the art to make and use the invention, and describes several embodiments, adaptations, variations, alternatives and uses of the invention, including what is presently believed to be the best mode of carrying out the invention.

As used herein, the terms “about” or “approximately” for any numerical values or ranges indicate a suitable dimensional tolerance that allows the part or collection of components to function for its intended purpose as described herein. Also, as used herein, the terms “body,” “patient,” “host,” and “subject” refer to any human or animal subject and are not intended to limit the systems or methods to human use, although use of the subject invention in a human patient represents a preferred embodiment.

Referring now to FIGS. 1A and 1B, a portion of an implantable prosthesis **10**, such as a stent-graft, is shown, including a substrate **100**, expandable segments **112**, **114**, **116**, and support members **150**. The implantable prosthesis is designed to collapse and expand radially in a uniform or non-uniform fashion. FIG. 1A shows the implantable prosthesis **10** in a generally collapsed configuration having a collapsed perimeter. FIG. 1B shows the implantable prosthesis **10** in an expanded configuration that defines an expanded perimeter larger than the collapsed perimeter. The scaffold **110** provides the radial strength of the prosthesis **10** to open a narrowed section of a lumen and maintain that section in an open position to permit blood flow there-through. The scaffold **110** can be a stent having a stent design, including a segmented stent design, a helical stent design, a solid stent design, or combinations thereof. The scaffold may have self-expanding properties, balloon-inflatable properties, or a combination thereof.

Support members **150** are connected to the scaffold and provide longitudinal stiffness/columnar strength in the collapsed configuration. The support members **150** may be made of the same material as the expandable members and can be either integral (e.g., first and second elements are formed with the expandable members during manufacture thereof) or attached as a separate elements. The support members in this embodiment include two elements **152** and **154**. The first element **152** connects to one expandable segment **112**, while the second element **154** connects to an adjacent expandable segment **114**. The first and second elements **152** and **154** are engaged in the collapsed configuration and are disengaged in the expanded configuration. The term “engaged” as used herein with respect to the various embodiments of first and second elements means at least some contact between the elements, which is generally maintained in the collapsed configuration of the prosthesis. Other terms with the same or similar meaning with respect to the first and second elements include, for example, coupled, connected, attached, etc. In the expanded configuration, the disengagement of support member elements results in a relative decrease in columnar strength for the prosthesis **10** but a relative increase in flexibility and fatigue resistance.

The implantable prosthesis **10** includes a graft or substrate layer **100**. This layer in one embodiment is a generally tubular polymer member disposed along the inner surface of the scaffold. The substrate **100** provides a base for the scaffold **100** and provides the prosthesis **10** with a smooth inner surface. The substrate **100** generally defines the longitudinal axis of the implantable prosthesis **10** and may be disposed along the length of the scaffold or only a portion thereof. The substrate **100** has a thickness generally in the range of approximately 10 microns to approximately 200 microns, and preferably in the range of approximately 20 microns to approximately 80 microns. The substrate **100** is flexible and compressible. Potential materials for a substrate include, for example, expanded polytetrafluoroethylene (ePTFE), polyester, polyurethane, fluoropolymers, polytetrafluoroethylene, silicones, urethanes, ultra high molecular weight polyethylene fibers, aramid fibers, and combinations thereof.

One preferred embodiment for a substrate material is ePTFE. The node-fibril microstructure of an ePTFE substrate may include various orientations for the fibrils, but preferably, the fibrils are oriented generally parallel to the longitudinal axis of the substrate. The average internodal distance of the substrate is preferably in the range of approximately 6 microns to approximately 80 microns. The substrate may include a bioactive agent and/or a carbon component along a blood contacting surface thereof. An ePTFE substrate may be manufactured in a number of ways, including, for example, extrusion of a tube (seamless), extrusion of a sheet that is subsequently formed into a tube (one or more seams), helical wrapping of ePTFE tape around a mandrel (e.g., multiple seams or preferably a single helical seam), etc.

The scaffold **110** provides radial strength to support a bodily lumen in an open position to permit blood flow and includes expandable segments **112**, **114**, **116** positioned along the longitudinal axis of the prosthesis **10**, and disposed over an outer surface of the substrate **100**. The expandable segments **112**, **114**, **116** are sufficiently elastic and radially rigid to remain open when inserted into a body lumen and are designed to radially collapse to aid in the delivery of the prosthesis into the body. The expandable segments in one embodiment may be formed of a shape memory material, including, for example, shape memory metals, shape memory alloys, super elastic shape memory metal alloys, linear elastic shape memory alloy, metal alloys, shape memory polymers, polymers, bio-resorbable material, and combinations thereof. One preferred shape memory material is Nitinol, while another is a cobalt chrome alloy. The sections may also be formed of metal, such as, for example, stainless steel, platinum, and Elgiloy, or certain polymers.

It should also be noted that one or more expandable segments and/or support members of the scaffold may be made of a bio-resorbable material. As used herein, the term "bio-resorbable" includes a suitable bio-compatible material, mixture of materials or partial components of materials being degraded into other generally non-toxic materials by an agent present in biological tissue (i.e., being bio-degradable via a suitable mechanism, such as, for example, hydrolysis) or being removed by cellular activity (i.e., bioresorption, bioabsorption, or bioresorbable), by bulk or surface degradation (i.e., bioerosion such as, for example, by utilizing a water insoluble polymer that is soluble in water upon contact with biological tissue or fluid), or a combination of one or more of the bio-degradable, bio-erodable, or bio-resorbable material noted above. Potential materials for the prosthesis described herein include, for example, biodegrad-

able polymers such as polylactic acid, i.e., PLA, polyglycolic acid, i.e., PGA, polydioxanone, i.e., PDS, polyhydroxybutyrate, i.e., PHB, polyhydroxyvalerate, i.e., PHV and copolymers or a combination of PHB and PHV (available commercially as Biopol®), polycaprolactone (available as Capronor®), polyanhydrides (aliphatic polyanhydrides in the back bone or side chains or aromatic polyanhydrides with benzene in the side chain), polyorthoesters, polyaminoacids (e.g., poly-L-lysine, polyglutamic acid), pseudo-polyaminoacids (e.g., with back bone of polyaminoacids altered), polycyanocrylates, or polyphosphazenes.

The scaffold may be connected to the substrate by various methods, which can be facilitated by the material selection for the scaffold, substrate and/or coatings, if utilized. An adhesive, a polymer bonded by a solvent, sutures, or other methods may be used to connect the scaffold to the substrate. Other alternatives known in the art are additionally within the scope of this invention, including weaving the substrate around the scaffold. The substrate may additionally be longitudinally compressed before attaching to the scaffold. The substrate is compressed from a first length to a second length, which is approximately 50% to 97% of the first length. Longitudinal compression of an ePTFE graft is described in U.S. Pat. No. 4,955,899 to Della Coma et al. and is incorporated by reference in its entirety in this application.

In one embodiment, an adhesive may be disposed between the scaffold and the substrate to bond the scaffold to the substrate at the interface between the expandable segments and the substrate. Suitable biocompatible bonding agents may include polytetrafluoroethylene, polyurethane, polyethylene, polypropylene, polyamides, polyimides, polyesters, polypropylenes, polyethylenes, polyfluoroethylenes, silicone fluorinated polyolefins, fluorinated ethylene/propylene copolymer, perfluoroalkoxy fluorocarbon, ethylene/tetrafluoroethylene copolymer, and polyvinylpyrrolidone. The bonding agent may constitute an interfacial layer between the scaffold and the substrate, or may be a polymeric cladding at least partially concentrically surrounding the scaffold. It should be noted that in embodiments in which the scaffold is adhered to the underlying substrate via an adhesive or bonding agent, the portions of the support members of the scaffold that are designed to translate with respect to other portions thereof when the prosthesis is expanded from a collapsed configuration to an expanded configuration (e.g., disengaging portions of a first or second element) should have the ability to do so following the bonding process.

In another embodiment, a polymer may be applied to the scaffold, and a solvent applied over the scaffold to bond the scaffold to the substrate. A suitable solvent may be an aprotic solvent including dimethylacetamide (DMSE), dimethylformamide, THF, or their mixtures. For example, in one embodiment a generally tubular ePTFE substrate is positioned over a mandrel. The substrate may be sintered, unsintered, or partially sintered. Using a loading tool, a predetermined number of discrete expandable segments (or an elongate member forming spaced apart expandable segments) with a polyurethane coating are positioned along the outer surface of the ePTFE substrate. Depending on the material properties of the expandable segments, an additional crimping step may be required to secure the segments in position. Once the expandable segments are initially positioned on a surface of the substrate, a laser alignment fixture is optionally utilized to optimally space the adjacent expandable segments with respect to one another. The mandrel is then removed from the assembly and a solvent, such as tetrahydrofuran (THF), may be applied to the inside surface of the ePTFE substrate,

so that the THF migrates through the wall of the ePTFE substrate. The interaction between the ePTFE, THF and polyurethane coating on the expandable segments bonds the segments to the ePTFE substrate (the THF or other aprotic solvent is believed to dissolve polyurethane, such that when a small amount contacts the polyurethane coating, a mechanical bond is developed between the coating and the ePTFE substrate).

In one embodiment, the expandable segments **110** are attached to the substrate **100** in an expanded configuration defining an expanded perimeter, the prosthesis **10** and expandable segments **110** later being radially compressed to a collapsed configuration defining a collapsed perimeter of the expandable segments smaller than the expanded perimeter for delivery to a blood vessel. As shown in FIGS. 1A and 1B, the expandable segments are discrete annular rings of connected struts. The expandable segments **112** include struts **124**, **126**, **128** arranged in an undulating configuration. Generally, the connected struts form a zig-zag pattern circumferentially around the prosthesis **10**. The intersection of adjacent struts **124**, **126** form an apex **120**. Apexes aligned on the same side of the expandable section **112** form a first set of apexes. A second set of apexes **122**, formed on the opposite side of the expandable section **112** by the intersection of different adjacent struts **126**, **128**, are offset from the first set of apexes **120**. Preferably, the annular expandable segment is closed ended, which results in an equal number of apex in each set.

The lengths of the struts **124**, **126**, **128** may be uniform, as shown, or may be varied about the circumference of the expandable segment. For example, the expandable segment **112** could include two or more strut lengths arranged in patterns about its circumference. Many other expandable segment configurations are also possible and within the scope of the invention, such as, for example, sinusoidal patterns, meandering curve patterns, other zigzag patterns, or other curvilinear patterns. Any type of pattern or shape can be combined with other patterns or shapes to form non-uniform expandable segments. Moreover, it should be appreciated that the shape, size, thickness, material and/or other characteristic of the circumferential sections can be varied along the length of the prosthesis **10**. Therefore, each expandable segment **112**, **114**, **116** need not be of the same material, shape, size, or configuration. Further, the undulations are not limited to zig-zag patterns but can be wave-like in form. The wave-like pattern can also be generally sinusoidal in that the pattern may have the general form of a sine wave, whether or not such wave can be defined by a mathematical function. Alternatively, any wave-like forms can be employed so long as it has amplitude and displacement. For example, a square wave, saw tooth wave, or any applicable wave-like pattern.

In one embodiment, expandable segments **112**, **114**, **116** are positioned along a surface of the substrate **100** so that a first set of apex **122** of one expandable segment **112**, aligns with the second set of apex **123** of an adjacent segment **114**. The adjacent annular members **112** and **114** are spaced a sufficient distance apart to prevent interference between the segments upon radial compression or tortuous bending of the prosthesis **10**. The expandable segments may be spaced at any sufficient distance to prevent interference and the spacing does not need to be uniform along the length of the prosthesis. Support members **150** extend generally transversely from the expandable segments **110** and are configured to engage and disengage as discussed above. Generally, the first and second elements are connected to adjacent expandable segments at a point near the adjacent segment.

For example, for the zig-zag configuration of FIGS. 1A-1B, the first element **152** of support member **150** extends from the apex **122** of a first expandable segment **112**, while the corresponding second element **154** extends from the apex **123** of the adjacent expandable segment **114**. It should be noted that the support members do not need to be positioned on each apex of the expandable segment, nor do they need to be longitudinally aligned along the length of the prosthesis.

The first element of support member **150** can engage with the second element of support member **150** in various different ways. As shown in FIGS. 1A-1B, the first element **152** has two legs **156** and **158**, while the second element **154** has a single leg **160**. When the prosthesis **10** is in the collapsed configuration, at least the distal end of the legs **156**, **158** contact at least the distal end of leg **160**, the leg **156** contacting a surface of leg **160** generally opposite of the surface of leg **160** contacted by leg **158** such that the first element **152** is engaged with the second element **154**. Upon expansion of the prosthesis **10** to an expanded configuration, the legs **156** and **158** of the first element **152** translate away from the leg **160** of the second element **154** such that the first element is disengaged from the second element **154**. In one embodiment, a majority of the length of the leg **160** is contacted on either side by legs **156** and **158** such that the second element leg **160** is substantially between the first element legs **156**, **158** in the collapsed configuration. In another embodiment, the first element and second element each include a single leg aligned and in contact when the prosthesis is in the collapsed configuration. The distal end of at least one of the first and second elements may include a detent or like feature in order to enhance the engagement contact therebetween in the collapsed configuration.

FIGS. 1C and 1D illustrate other potential embodiments of the scaffold. In FIG. 1C, scaffold **130** is formed from individual, discrete, annular members. The annular members **132** and **134** are configured in a closed cell lattice formation. The annular members may be in a single closed cell lattice, **132**, or multiple closed cell lattice, **134**, or combinations thereof. The lattice is composed of connected struts **136**, which may be generally straight, as shown, or curved, such that the closed cell **138** may assume several possible geometric shapes. Preferably, the annular members are cut from a tube of shape memory material (e.g., Nitinol). For example, longitudinal slits are laser cut into a solid Nitinol tube in such a manner as to form the desired closed cell configuration upon expansion of the tube. It should be appreciated that other methods of forming the annular members are possible and within the scope of the invention. For example, the single annular rings described above may be joined or connected together to form the single or plural closed cell lattice.

In FIG. 1D, the scaffold **140** includes one or more elongate members helically disposed about an outer surface of a substrate **100** from a first end of the prosthesis **10** to a second end. The distance between adjacent helical windings **142**, **144** of elongate member **140** may be approximately equal along the length of the prosthesis **10**, or may vary along the length. For example, beginning at one end of the prosthesis **10**, the distance between the first two helical windings, **142** and **144**, could be more or less than the distance between subsequent helical windings. The distance between adjacent helical windings could then progressively become greater or shorter along the length of the prosthesis, or could alternate between various distances. In embodiments including two or more elongate members, the mem-

bers could be helically wound about the substrate in different directions and/or with different helical angles.

In one embodiment, the elongate member **140** includes struts **146** arranged generally in a zig-zag pattern, including a longer first strut and shorter adjacent strut that alternate along the length of the elongate member **140**. The first, longer strut and second, shorter strut intersect at an apex **148**. Adjacent pairs of struts will form two sets of apexes on alternate sides of the helical winding, which are offset from each other. The helical windings of an elongate member are positioned so that the first set of apexes on one helical winding is aligned with the second set of apexes from an adjacent helical winding. The adjacent windings are, additionally, spaced a sufficient distance apart to prevent interference between the windings upon radial compression or tortuous bending of the prosthesis. Therefore, the distance between adjacent helical windings is such that regardless of alignment, radial compression of the prosthesis will not result in interlocking the struts. Many other configurations are also possible for the elongate member **140** and are within the scope of the invention, such as, for example, sinusoidal patterns, meandering curve patterns, other zigzag patterns, or other curvilinear patterns. Any type of pattern or shape can be combined with other patterns or shapes to form non-uniform windings. Moreover, as discussed above, it should be appreciated that the shape, size, thickness, material and/or other characteristic of the elongate members can be varied along the length of the scaffold.

FIGS. 2A-2B illustrate support member **150**, including first and second elements, **152** and **154**, in the collapsed and expanded configuration. The first element **152** has two legs, **200** and **202**, connected to the an expandable segment (not shown), while the second element **154** has a single leg **204** connected to an adjacent expandable section (not shown). Other embodiments include single legs for each of the first and second elements (FIGS. 3A-3C), two or more legs for each of the first and second elements where the number of legs for each is the same, and two or more legs for each of the first and second elements where the number of legs for each is different. As seen in FIG. 2A, when the support member **250** is in the collapsed configuration, the first and second elements **152**, **154** generally align, and the distal portions, **220** and **222**, of the legs **200** and **202** of the first element **152** are adjacent and substantially parallel. Both first and second elements, **152** and **154**, are generally aligned with the longitudinal axis of the prosthesis. When the prosthesis is in the collapsed configuration, the distal ends of the first element **210**, **212** are in contact with, or spaced a short distance from (e.g., less than about 100 microns), the distal end of the second element **214**. In the case where slight spacing is present, the distal ends of the first element **210**, **212** may come in contact with the distal ends of the second element **214** when the prosthesis is subject to compressive forces during deployment thereof (e.g., withdrawal of a delivery sheath from a constraining position over the prosthesis). When the prosthesis is expanded to the expanded configuration, the legs **200** and **202** of the first element **152** move in approximately opposite circumferential directions, as indicated by the arrows **230**, **232** (FIG. 2B), such that the distal portions **220** and **222** of the legs **200** and **202** are spaced apart from each other and the distal ends **210**, **212** of the legs **200** and **2002** are spaced apart from distal end **214** of the leg **204**.

In another embodiment, shown in FIG. 3A, the support member **150** has first and second elements **152** and **154**, each of the first and second elements including a single leg **300** and **302** connected to adjacent expandable segments (not

shown). Both legs **300** and **302** are generally aligned and parallel to the longitudinal axis of the prosthesis. When the support member **150** is in the collapsed configuration, the distal ends **304** and **306** of legs **300** and **302** are in contact with one another or spaced a short distance apart (e.g., less than about 100 microns). In the case where slight spacing is present, the distal ends **304** and **306** may come in contact when the prosthesis is subject to compressive forces during deployment thereof. Upon expansion of the prosthesis to the expanded configuration, the legs **300**, **302** of the first and second elements **152**, **154** disengage (e.g., are no longer in contact) through translation of one or both of the legs to a position that is no longer aligned with the longitudinal axis (i.e., the leg generally forms an oblique angle with respect thereto by translating in a circumferential direction).

FIG. 3B shows the prosthesis in the expanded configuration, whereby leg **300** translates with respect to leg **302**, which remains generally in the same position as in the collapsed configuration shown in FIG. 3A. FIG. 3C shows both legs **300**, **302** translating to a position generally oblique to the longitudinal axis, the legs moving in different circumferential directions as indicated by arrows **320**, **322**. In another embodiment, the legs **300** and **302** are configured to move in the same general circumferential direction upon expansion of the prosthesis to an expanded configuration. In one embodiment, in addition to, or instead of, translating in a circumferential direction, one or more of the legs of the first and second elements will translate in a direction away from the central longitudinal axis of the prosthesis during expansion to the expanded configuration such that the distal ends of the legs may become embedded in a wall of the cavity or vessel into which the prosthesis is deployed. Thus, the legs may assist in preventing migration of the stent-graft, although it should be appreciated that the legs in most embodiments are sufficiently small to avoid complete penetration or perforation of the walls of the vessel. FIG. 3D shows one example of such an embodiment, in which leg **310** moves in the direction indicated by arrow **324**, away from the central axis of the prosthesis when the prosthesis is expanded to an expanded configuration (i.e., distal end **304** moves out of the plane of the page toward the viewer).

FIG. 4A illustrates an embodiment of the first and second elements **152**, **154**, in which the distal ends **420**, **422**, and **424** of the legs thereof include complementary shapes. In the example shown, the distal ends **420** and **422** of the legs **410** and **412** are inwardly beveled in such a manner that when adjacent (i.e., when the prosthesis is in the collapsed configuration), they together form generally a "V" shape. Complementary, the distal end **424** of leg **414** includes a pointed configuration that extends into the "V" shape when the prosthesis is in the collapsed configuration. Complementary shapes for the distal ends of the first and/or second element of the support members therein may aid in preventing misalignment of the elements during loading and delivery of the prosthesis. Further, in one embodiment, a friction fit may be formed between the first element **152** and the second element **154** to further enhance the engagement. Other configurations are also possible and fall within the scope of the present invention. For example, the distal end of a first and second leg of the first element may form an inverted cone when collapsed and the distal end of the second element may form a complementary shape to extend into the inverted cone. Alternatively, the distal end of a first and second leg of the first element may have a cube edge or cylindrical indentation to receive a complementary distal end of one or more legs of the second element.

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FIGS. 4B-4C illustrate other configurations for the complementary shapes of the distal ends of the first and second elements 152, 154. In these examples, different from the example in FIG. 2A, both the first element 152 and second element 154 include single legs with complementary shaped distal ends and the second element 154 distal end includes a detent-like feature while the first element 152 distal end includes a complementary-shaped protrusion. Of course, as with any of the embodiments described herein, the first and second elements may have distal end shapes that are reversed. FIG. 4B shows a "U" shaped detent on the distal end 436 of leg 432 of the second element 154, which is complemented by a rounded protrusion on the distal end 434 of leg 430 of the first element 152. FIG. 4C shows a "V" shaped detent on the distal end 446 of leg 442 of the second element 154 which is complemented by a "W" shaped protrusion on the distal end 444 of leg 440 of the first element 152. Of course, these examples should be considered non-limiting as other complementary shapes are also possible and within the scope of the invention.

FIG. 5 illustrates prosthesis 50 in its expanded configuration, featuring an optional outer layer 500. Outer layer 500 may provide additional support for the prosthesis 50 and/or a means for coupling the scaffold to the substrate in addition to, or instead of, other coupling methods, such as, for example, selective application of adhesives, application of a polymer to the annular members and bonding with a solvent, use of sutures to stitch the annular members to the substrate, etc. Outer layer 500 includes a plurality of circumferential bands, such as bands 502, 504, and 506, which are positioned over an outer surface of the expandable segments 512, 514, and 516, and are bonded to the substrate 100 at spaced apart locations. The bands are positioned such that support members 150 are substantially uncovered, including the first and second elements 152, 154, thereby permitting translation thereof when the prosthesis is expanded from the collapsed configuration to the expanded configuration and vice versa. In another embodiment, the substrate is positioned on an outer surface of the expandable segments 510, while the circumferential bands are positioned along an inner surface thereof.

The circumferential bands may be continuous, closed rings of material, or longitudinal strips of material with a first and second end that are circumferentially wrapped over the scaffold such that the first and second ends overlap. In other embodiments, longitudinal strips of material are used in combination with, or instead of, the circumferential bands. The longitudinal strips may be arranged over the scaffold outer surface such that it is aligned generally parallel to the longitudinal axis of the prosthesis or at an oblique angle therewith. One or more elongate strips of material may, in addition to or instead of the circumferential bands, be helically wound about the scaffold and substrate with a constant pitch or one that varies along the length of the prosthesis. The circumferential bands, longitudinal strip(s) and elongate strip(s) may include a material such as, for example, polytetrafluoroethylene, expanded polytetrafluoroethylene, fine metal meshes, linear polyethylene, polymers, combinations thereof, and/or any of the materials discussed above as potential materials for the substrate.

In a preferred embodiment, the outer layer 500 and substrate 100 are made of expanded polytetrafluoroethylene. In one embodiment, the outer layer 500 is brought into contact with the substrate through gaps in the expandable segment by applying inward pressure to the outside of the outer layer (e.g., by wrapping with tape), outward pressure to the inner surface of the substrate (e.g., by using a medical

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balloon), or both. The assembly is then subject to a heating process to bond the outer layer 500 to the substrate 100. For example, the assembly may be heated to a temperature above the melting point of the material from which the outer layer and substrate are formed so that the two materials flow together and remain interlocked upon cooling. Alternatively, the outer surface may be heated at discrete bonding locations to sinter the outer layer to the substrate at the bonding locations.

The prosthesis, as described herein, may be implanted into a patient to open and hold open a body lumen. One method of delivery of the prosthesis to a body lumen includes first placing the prosthesis into a delivery device. The prosthesis may be formed/assembled in the expanded configuration, meaning that it would first need to be collapsed into its collapsed configuration for insertion into the delivery device, or alternatively may be formed/assembled in a collapsed configuration. As discussed above, the elements of the support members are engaged in the collapsed configuration. The delivery device including the prosthesis is then introduced into a body lumen, for example, and deployed as known to one skilled in the art (e.g., by removal of a sheath whereby a self-expandable prosthesis expands in the absence of a constraining force, by balloon expanding the prosthesis, or some combination thereof). During deployment, the prosthesis is radially expanded to an expanded configuration, which expansion results in the decoupling or disengaging of the elements of the support members. Also, in some embodiments, one or more elements of the support members may become embedded in the vessel wall to prevent migration of the prosthesis. Following expansion of the prosthesis, the delivery device is removed from the patient.

Markers M1, M2, M3, M4 . . . Mn can be provided for all of the embodiments described herein. One or more markers may be positioned along the longitudinal axis of the prosthesis. The marker Mn can be formed from the same material as the stent as long as the material is radiographic or radiopaque. The marker material can also be formed, for example, from gold, tantalum, platinum, iridium, barium, sulfate, Nitinol, Hydroxyapatite, and combinations thereof. One or more markers can be formed from a marker material different from other markers.

The prosthesis described herein may be utilized with bio-active agents. Bio-active agents can be coated onto a portion or the entirety of the prosthesis, substrate, or circumferential bands for controlled release of the agents once the prosthesis is implanted. The bio-active agents can include, but are not limited to, vasodilator, anti-coagulants, such as, for example, warfarin and heparin. Other bio-active agents can also include, but are not limited to agents such as, for example, anti-proliferative/antimitotic agents including natural products such as vinca alkaloids (i.e. vinblastine, vincristine, and vinorelbine), paclitaxel, epididodophyllotoxins (i.e. etoposide, teniposide), antibiotics (dactinomycin (actinomycin D) daunorubicin, doxorubicin and idarubicin), anthracyclines, mitoxantrone, bleomycins, plicamycin (mithramycin) and mitomycin, enzymes (L-asparaginase which systemically metabolizes L-asparagine and deprives cells which do not have the capacity to synthesize their own asparagine); antiplatelet agents such as G(GP) IIb/IIIa inhibitors and vitronectin receptor antagonists; anti-proliferative/antimitotic alkylating agents such as nitrogen mustards (mechlorethamine, cyclophosphamide and analogs, melphalan, chlorambucil), ethylenimines and methylmelamines (hexamethylmelamine and thiotepa), alkyl sulfonates-busulfan, nirtosoureas (carmustine (BCNU) and

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analogs, streptozocin), trazenes-dacarbazine (DTIC); anti-proliferative/antimitotic antimetabolites such as folic acid analogs (methotrexate), pyrimidine analogs (fluorouracil, floxuridine, and cytarabine), purine analogs and related inhibitors (mercaptopurine, thioguanine, pentostatin and 2-chlorodeoxyadenosine {cladribine}); platinum coordination complexes (cisplatin, carboplatin), procarbazine, hydroxyurea, mitotane, aminoglutethimide; hormones (i.e. estrogen); anti-coagulants (heparin, synthetic heparin salts and other inhibitors of thrombin); fibrinolytic agents (such as tissue plasminogen activator, streptokinase and urokinase), aspirin, dipyridamole, ticlopidine, clopidogrel, abciximab; antimigratory; antisecretory (breveldin); anti-inflammatory: such as adrenocortical steroids (cortisol, cortisone, fludrocortisone, prednisone, prednisolone, 6 $\alpha$ -methylprednisolone, triamcinolone, betamethasone, and dexamethasone), non-steroidal agents (salicylic acid derivatives i.e. aspirin; para-aminophenol derivatives i.e. acetaminophen; indole and indene acetic acids (indomethacin, sulindac, and etodolac), heteroaryl acetic acids (tolmetin, diclofenac, and ketorolac), arylpropionic acids (ibuprofen and derivatives), anthranilic acids (mefenamic acid, and meclofenamic acid), enolic acids (piroxicam, tenoxicam, phenylbutazone, and oxyphenbutazone), nabumetone, gold compounds (auranofin, aurothioglucose, gold sodium thiomalate); immunosuppressives: (cyclosporine, tacrolimus (FK-506), sirolimus (rapamycin), azathioprine, mycophenolate mofetil); angiogenic agents: vascular endothelial growth factor (VEGF), fibroblast growth factor (FGF); angiotensin receptor blockers; nitric oxide donors; anti-sense oligonucleotides and combinations thereof; cell cycle inhibitors, mTOR inhibitors, and growth factor receptor signal transduction kinase inhibitors; retinoids; cyclin/CDK inhibitors; HMG co-enzyme reductase inhibitors (statins); and protease inhibitors.

This invention has been described and specific examples have been portrayed. While the invention has been described in terms of particular variations and illustrative figures, those of ordinary skill in the art will recognize that the invention is not limited to the variations or figures described. In addition, where methods and steps described above indicate certain events occurring in certain order, those of ordinary skill in the art will recognize that the ordering of certain steps may be modified and that such modifications are in accordance with the variations of the invention. Additionally, certain of the steps may be performed concurrently in a parallel process when possible, as well as performed sequentially as described above. Therefore, to the extent there are variations of the invention, which are within the spirit of the disclosure or equivalent to the inventions found in the claims, it is the intent that this patent will cover those variations as well. Finally, all publications and patent applications cited in this specification are herein incorporated by reference in their entirety as if each individual publication or patent application were specifically and individually put forth herein.

What is claimed is:

1. An implantable prosthesis having a fully expanded configuration defining an expanded perimeter and a collapsed configuration defining a collapsed perimeter smaller than the expanded perimeter comprising:

- a generally tubular substrate defining a longitudinal axis;
- a scaffold disposed over the substrate including a series of longitudinally adjacent expandable rings formed of alternating struts;
- a plurality of support members extending between longitudinally adjacent expandable rings, each support member including a first element coupled to and

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extending from an apex formed at a connection between two adjacent struts of an expandable ring and a second element coupled to and extending from an apex formed at a connection between two adjacent struts of an adjacent expandable ring,

wherein the first element comprises a first linear leg and a second linear leg and the second element comprising a third linear leg, and, in the collapsed configuration, the first linear leg, the second linear leg, and the third linear leg are parallel, terminal end regions of the first linear leg and the second linear leg contact along a common longitudinal length to define a linear element collinear to the second element such that terminal ends of the first element and the second element contact each other,

wherein in the fully expanded configuration, the terminal end regions of the first linear leg and the second linear leg are separated circumferentially along the common longitudinal length to form oblique angles with the longitudinal axis, and the terminal ends of the first element and the second element do not contact,

wherein the first linear leg and second linear leg originate from a common apex, inside lateral edges of the first linear leg and second linear leg are in contact in the collapsed configuration and out of contact in the expanded configuration, and one of the first element and second element includes a terminal distal end surface defining a detent and the other of the first element and second element includes a terminal distal end surface defining a shape configured to extend into the detent and form a friction fit therewith; the implantable prosthesis further comprising

a plurality of circumferential bands, such bands bonded to the substrate at spaced apart locations, the bands positioned over an outer surface of the expandable rings such that the plurality of support members are substantially uncovered;

one or more radiopaque markers positioned along the implantable prosthesis; and

a bio-active agent coated onto a portion of the implantable prosthesis.

2. The implantable prosthesis according to claim 1 wherein a configuration of the detent is selected from the group consisting essentially of "U" shaped, "V" shaped, "W" shaped, and combinations thereof.

3. The implantable prosthesis according to claim 1 wherein a distal portion of the first linear leg is positioned adjacent to and in contact with a distal portion of the second linear leg in the collapsed configuration, a terminal distal end of the third linear leg in contact with a terminal distal end of the first linear leg and a terminal distal end of the second linear leg.

4. The implantable prosthesis according to claim 3 wherein the distal portion of the first linear leg is positioned apart from the distal portion of the second linear leg in the fully expanded configuration, the terminal distal end of the third linear leg out of contact with the terminal distal ends of the first linear leg and the second linear leg.

5. The implantable prosthesis according to claim 1 wherein a proximal end of the first linear leg and a proximal end of the second linear leg are connected to the apex at a common vertex such that expansion to the fully expanded configuration moves the first linear leg and the second linear leg in approximately opposite directions.

6. The implantable prosthesis according to claim 5 wherein the first linear leg and the second linear leg together form a "V" shape in the fully expanded configuration.

7. The implantable prosthesis according to claim 1 wherein the first linear leg and the second linear leg include

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beveled distal ends that together form a “V” shape in the collapsed configuration, the third linear leg including a distal end configured to extend into the “V” shape.

8. The implantable prosthesis according to claim 1 wherein the first linear leg and the second linear leg are positioned parallel to the longitudinal axis of the substrate in the collapsed configuration.

9. The implantable prosthesis according to claim 8 wherein at least one of the first linear leg and the second linear leg is positioned generally oblique to the longitudinal axis in the fully expanded configuration.

10. The implantable prosthesis according to claim 9 wherein the first linear leg and the second linear leg move in approximately opposite directions upon expansion to an expanded configuration.

11. The implantable prosthesis according to claim 8 wherein at least one of the first linear leg and the second linear leg move in a direction out of a surface defined by the series of longitudinally adjacent expandable rings upon expansion to an expanded configuration.

12. The implantable prosthesis according to claim 1 wherein a distal portion of the first linear leg is positioned adjacent to a distal portion of the second linear leg in the collapsed configuration, a distal end of the third linear leg spaced less than about 100 microns from a distal end of the first linear leg and a distal end of the second linear leg.

13. The implantable prosthesis according to claim 1 wherein a distal portion of the first linear leg is positioned adjacent to a distal portion of the second linear leg in the

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collapsed configuration, a distal end of the third linear leg in contact with a distal end of the first linear leg and a distal end of the second linear leg.

14. The implantable prosthesis according to claim 13 wherein the distal portion of the first linear leg is positioned apart from the distal portion of the second linear leg in the fully expanded configuration, the distal end of the third linear leg out of contact with the distal ends of the first linear leg and the second linear leg.

15. The implantable prosthesis according to claim 1 wherein a proximal end of the first linear leg and a proximal end of the second linear leg are connected to a common longitudinal apex of the expandable ring such that expansion to the fully expanded configuration moves the first linear leg and the second linear leg in approximately opposite directions.

16. The implantable prosthesis according to claim 1 wherein the first linear leg and the second linear leg include beveled distal ends that together form a “V” shape in the collapsed configuration, the third linear leg including a distal end configured to extend into the “V” shape.

17. The implantable prosthesis according to claim 1 wherein the first linear leg and the second linear leg move in approximately opposite directions upon expansion to the fully expanded configuration.

18. The implantable prosthesis according to claim 1 wherein at least one of the first linear leg and the second linear leg move in a direction out of a surface defined by the series of longitudinally adjacent expandable rings upon expansion to the fully expanded configuration.

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